Unsteady Leakage Flow through Axial Clearance of an ORC Scroll Expander

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2. Methodology
   - Geometric model; Numerical model and solution method
3. Results and discussion
   - Unsteady performance; Effects of radial leakage on flow field
4. Conclusions
Introduction

Classification

Volumetric type
- Scroll
- Screw
- Piston
- Gerotor
- Rotary vane
- Rolling rotor

Velocity type
- Turbine
Introduction

Scroll expander

- High efficiency
- Compact structure
- Low speed
- Low noise
- High reliability

Internal clearance leakage

External leakage

Heat dissipation

Mechanical friction

Efficiency reduction
Introduction

- Interfering with the flows in the upstream/downstream gas chambers
- Reduction of gas expansion capacity in gas chambers
- Increment of the energy losses in gas chambers
Introduction

- Isentropic compressible nozzle flow model
- Compressible adiabatic flow with Fanno flow model
- Incompressible and viscous pipe flow model
- One-dimensional laminar flow model
- Incompressible, viscous and turbulent flow model

- Unsteady behaviors of radial leakage flow
- Influences on the gas flow in working chamber
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Methodology

- Geometric model of STE

![Overall view](image1.png)

![Cross-section view](image2.png)

 Specifications of scroll compressor

<table>
<thead>
<tr>
<th>Displacement</th>
<th>Speed range</th>
<th>Motor type</th>
<th>Nominal Voltage</th>
<th>Voltage range</th>
</tr>
</thead>
<tbody>
<tr>
<td>34 ml/r</td>
<td>2500~8000rpm</td>
<td>Brushless DC</td>
<td>DC 330V</td>
<td>DC 0~400V</td>
</tr>
</tbody>
</table>
Geometric model of STE

- Constant scroll wrap thickness (basic circle)
- Double arc modification of top profile
Methodology

- Geometric model of STE
  - Point coordinates on the basic circle involute

Inner Involute:
\[
\begin{align*}
x_i &= r_b (\cos \varphi_i + (\varphi_i - \alpha_i) \sin \varphi_i) \\
y_i &= r_b (\sin \varphi_i - (\varphi_i - \alpha_i) \cos \varphi_i)
\end{align*}
\]

Outer Involute:
\[
\begin{align*}
x_o &= r_b (\cos \varphi_o + (\varphi_o - \alpha_o) \sin \varphi_o) \\
y_o &= r_b (\sin \varphi_o - (\varphi_o - \alpha_o) \cos \varphi_o)
\end{align*}
\]

Design parameters: \((r_b, \alpha_i, \alpha_o, \varphi_e, \beta, \gamma)\)
## Methodology

### Geometric model of STE

<table>
<thead>
<tr>
<th>Parameters</th>
<th>$r_b$</th>
<th>$R_{or}$</th>
<th>$t$</th>
<th>$P$</th>
<th>$\alpha$</th>
<th>$\beta$</th>
<th>$\gamma$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit</td>
<td>(mm)</td>
<td>(mm)</td>
<td>(mm)</td>
<td>(mm)</td>
<td>(rad)</td>
<td>(rad)</td>
<td>(rad)</td>
</tr>
<tr>
<td>Value</td>
<td>2.39</td>
<td>4.2</td>
<td>3.3</td>
<td>15</td>
<td>0.69</td>
<td>0.373</td>
<td>0.247</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameters</th>
<th>$\phi_{s, in}$</th>
<th>$\phi_{s, ou}$</th>
<th>$\phi_e$</th>
<th>$H$</th>
<th>$D$</th>
<th>$d_{suc}$</th>
<th>$d_{dis}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit</td>
<td>(rad)</td>
<td>(rad)</td>
<td>(rad)</td>
<td>(mm)</td>
<td>(mm)</td>
<td>(mm)</td>
<td>(mm)</td>
</tr>
<tr>
<td>Value</td>
<td>3.515</td>
<td>0.373</td>
<td>16.06</td>
<td>24</td>
<td>87.4</td>
<td>6</td>
<td>13.5</td>
</tr>
</tbody>
</table>
Methodology

- Numerical model and solution method

Mesh generation of fluid domain
Methodology

- Numerical model and solution method

Mesh generation of fluid domain

Deformed surface

Orbiting scroll

Undeformed surface

Fixed scroll
Methodology

- **Numerical model and solution method**
  - RNG k-e turbulence model
  - Standard wall function
  - First order backward difference scheme
  - Second order upwind scheme
  - PRESTO (Pressure staggered option) scheme
  - Second order central difference scheme
  - PISO algorithm
Methodology

- Numerical model and solution method

1kW solar-ORC system

Operating condition of STE

<table>
<thead>
<tr>
<th></th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inlet pressure</td>
<td>MPa</td>
<td>1.1</td>
</tr>
<tr>
<td>Inlet temperature</td>
<td>K</td>
<td>378</td>
</tr>
<tr>
<td>Outlet pressure</td>
<td>MPa</td>
<td>0.3</td>
</tr>
<tr>
<td>Rotating speed</td>
<td>r/min</td>
<td>3200</td>
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<tr>
<td>Working fluid</td>
<td>-</td>
<td>r245fa</td>
</tr>
</tbody>
</table>

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Results and discussion

- **Expander transient performance**

- Higher mass flow rate
- Lower discharge flow fluctuation
- Different discharge flow capacity
- Reverse discharge flow
Results and discussion

- Expander transient performance

\[ F_t = \sum_{i=1}^{n} \left( F_{y,i} \cos \left( \frac{\pi N}{30} t \right) - F_{x,i} \sin \left( \frac{\pi N}{30} t \right) \right) \]

\[ M_t = R_{or} \sum_{i=1}^{n} F_{t,i} \]

\[ \xi = \sqrt{\frac{1}{N} \sum_{j=1}^{N} (\phi_j - \bar{\phi})^2 / \bar{\phi}} \]

- Smaller gas driving moment
- Smaller fluctuating coefficient
- Effects of discharge flow
Results and discussion

- **Velocity distribution in axial clearances**

  - Radial leakage between *asymmetrical* chambers
  - Radial leakage between *symmetrical* chambers
Results and discussion

- **Velocity distribution in axial clearances**

  - Asymmetric velocity distribution between two axial clearances
Results and discussion

- Pressure distribution in axial clearances

- Pressure gradient at clearance inlet between asymmetric chambers
- Non-uniform pressure in axial clearance along the scroll involute
- Pressure distortion occurs in the downstream of axial clearance
Results and discussion

- Pressure distribution in axial clearances

Top axial clearance
Results and discussion

- Effects of radial leakage in working chambers

- Low pressure region in symmetric working chambers
- Vortices: Leakage flow, fluid viscous force, wall constraint
Results and discussion

- **Effects of radial leakage in working chambers**

  - Stronger vortex flow nearby top axial clearance
  - Pressure distortion in the expansion chambers at the scroll tip and root
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Radial leakage flows occur at not only the axial clearances of the scroll segments between *asymmetrical* chambers but also those between *symmetrical* chambers.

Radial leakage flows through the top and bottom axial clearances are *approximately symmetrical* about the meshing line.

*Non-uniform pressure distribution* in the axial clearance passage exists along the scroll involute direction.

*Large pressure distortion* occurs in the downstream of the axial clearance between asymmetric working chambers.

Radial leakage flow leads to *secondary vortex flow* and *non-uniform pressure distribution* in working chambers.
Thanks for your attention!
Questions are welcome!

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